



Physics with Tagged Protons at STAR

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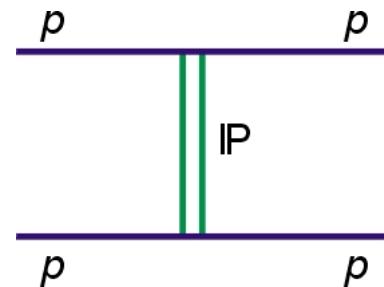
for the STAR collaboration

Creighton University
RHIC and AGS Users'
Annual Meeting 2010
BNL, Upton, NY

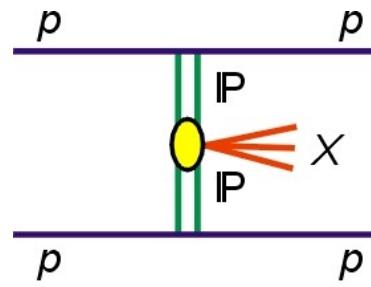
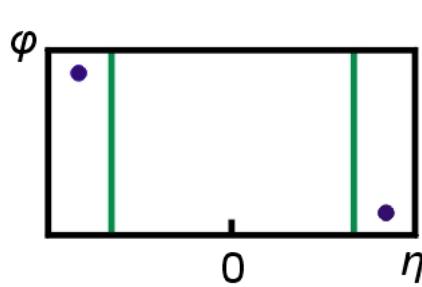
Diffractive Physics Program at RHIC



QCD color singlet exchange: C=+1, C=-1

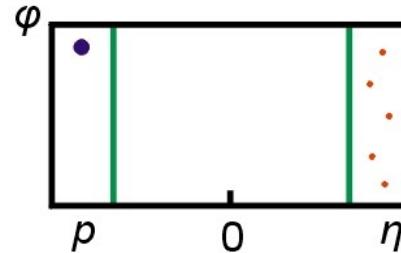
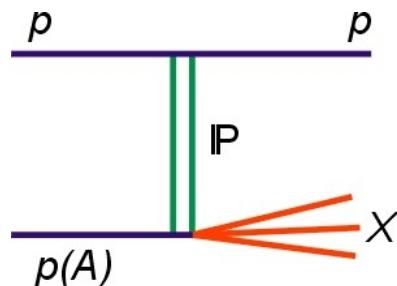
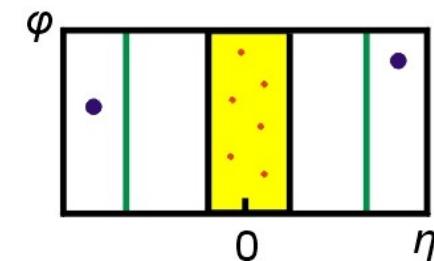


$p + p \rightarrow p + p$
elastic



$p + p \rightarrow p + X + p$

Double Pomeron Exchange (DPE)
diffractive X= particles, glueballs



Single Diffraction Dissociation (SDD)

Cross Section

Cross section azimuthal dependence for transversely polarized beam

$$\sigma = \sigma_0 [1 + A_N (P_B + P_Y) \cdot n + A_{NN} (P_B \cdot n)(P_Y \cdot n) + A_{SS} (P_B \cdot s)(P_Y \cdot s)]$$

$A_N = \frac{\sigma^{\uparrow\uparrow} - \sigma^{\downarrow\downarrow}}{\sigma^{\uparrow\uparrow} + \sigma^{\downarrow\downarrow}}$ - single spin asymmetry. $\sigma^{\uparrow\uparrow}$ - cross-section for one beam fully polarized along normal n to the scattering plane.

$A_{NN} = \frac{\sigma^{\uparrow\uparrow+\downarrow\downarrow} - \sigma^{\uparrow\downarrow+\downarrow\uparrow}}{\sigma^{\uparrow\uparrow+\downarrow\downarrow} + \sigma^{\uparrow\downarrow+\downarrow\uparrow}}$ - double spin asymmetry. $\sigma^{\uparrow\uparrow+\downarrow\downarrow}$ - cross-section for both beams fully polarized along the unit vector n normal to the scattering plane.

A_{SS} has the same definition as A_{NN} , but $\sigma^{\uparrow\uparrow+\downarrow\downarrow}$ is a cross-section for both beams fully polarized along the unit vector in the scattering plane along axis s :

$$s = \frac{\vec{n} \times \vec{p}}{|\vec{n} \times \vec{p}|}, \text{ where } p - \text{beam momentum.}$$

P_B - blue beam polarization vector

P_Y - yellow beam polarization vector

Helicity Amplitudes in Elastic Scattering



Five helicity amplitudes describe proton-proton elastic scattering

$$\phi_1(s,t) \propto \langle ++ | M | ++ \rangle \leftarrow \text{non-flip}$$

$$\phi_2(s,t) \propto \langle ++ | M | -- \rangle \leftarrow \text{double-flip}$$

$$\phi_3(s,t) \propto \langle +- | M | +- \rangle \leftarrow \text{non-flip}$$

$$\phi_4(s,t) \propto \langle +- | M | -+ \rangle \leftarrow \text{double-flip}$$

$$\phi_5(s,t) \propto \langle ++ | M | +- \rangle \leftarrow \text{single-flip}$$

$$\phi_i(s,t) = \phi_i^{em}(s,t) + \phi_i^{had}(s,t)$$

$$\phi_+ = \frac{1}{2}(\phi_1 + \phi_3)$$

$$\phi_- = \frac{1}{2}(\phi_1 - \phi_3)$$

$$\phi_i^{had} = \phi_i^R + \phi_i^{\text{Asympt.}}$$

Some of the measured quantities are:

$$\sigma_{tot} = \frac{4\pi}{s} \text{Im}\{ \phi_1 + \phi_3 \}_{t=0}$$

$\frac{d\sigma}{dt} = \frac{4\pi}{s^2} (\phi_1^2 + \phi_2^2 + \phi_3^2 + \phi_4^2 + \phi_5^2)$ contributes to the shape of A_N

$$A_N(s,t) \frac{d\sigma}{dt} = \frac{-4\pi}{s^2} \text{Im}\{ \phi_5^*(\phi_1 + \phi_2 + \phi_3 - \phi_4) \}$$

$$A_{NN}(s,t) \frac{d\sigma}{dt} = \frac{4\pi}{s^2} \left\{ 2|\phi_5|^2 + \text{Re}(\phi_1^*\phi_2 - \phi_3^*\phi_4) \right\}$$

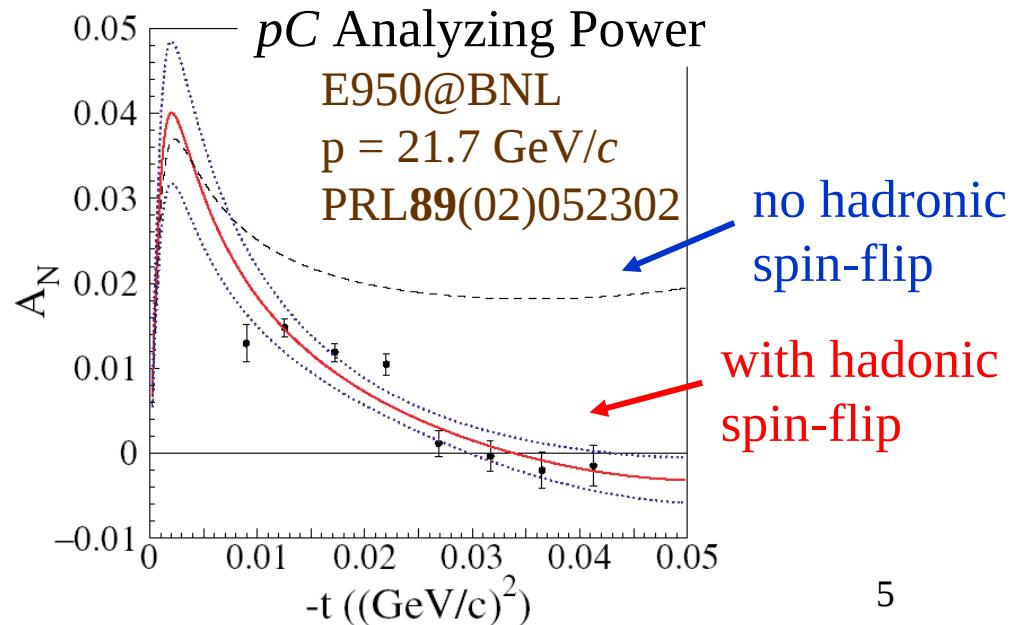
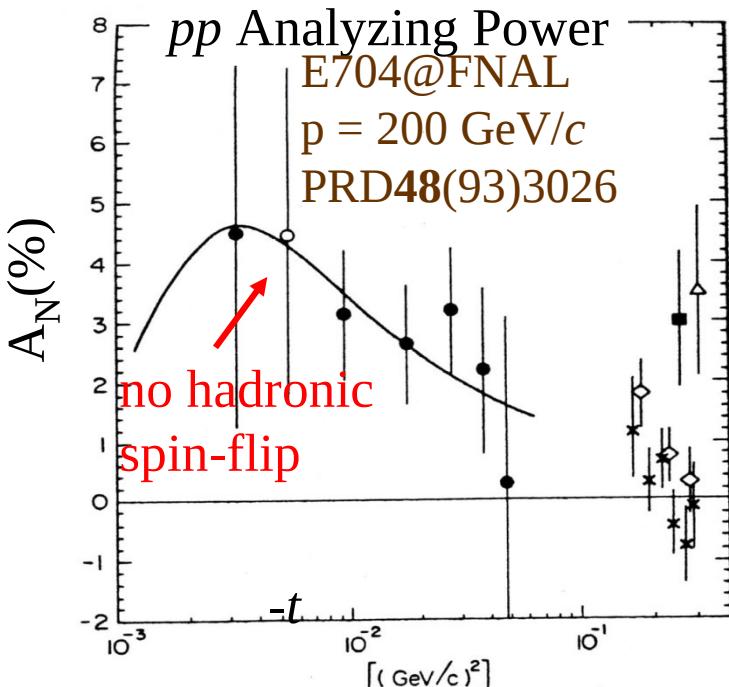
Single Spin Analyzing Power A_N



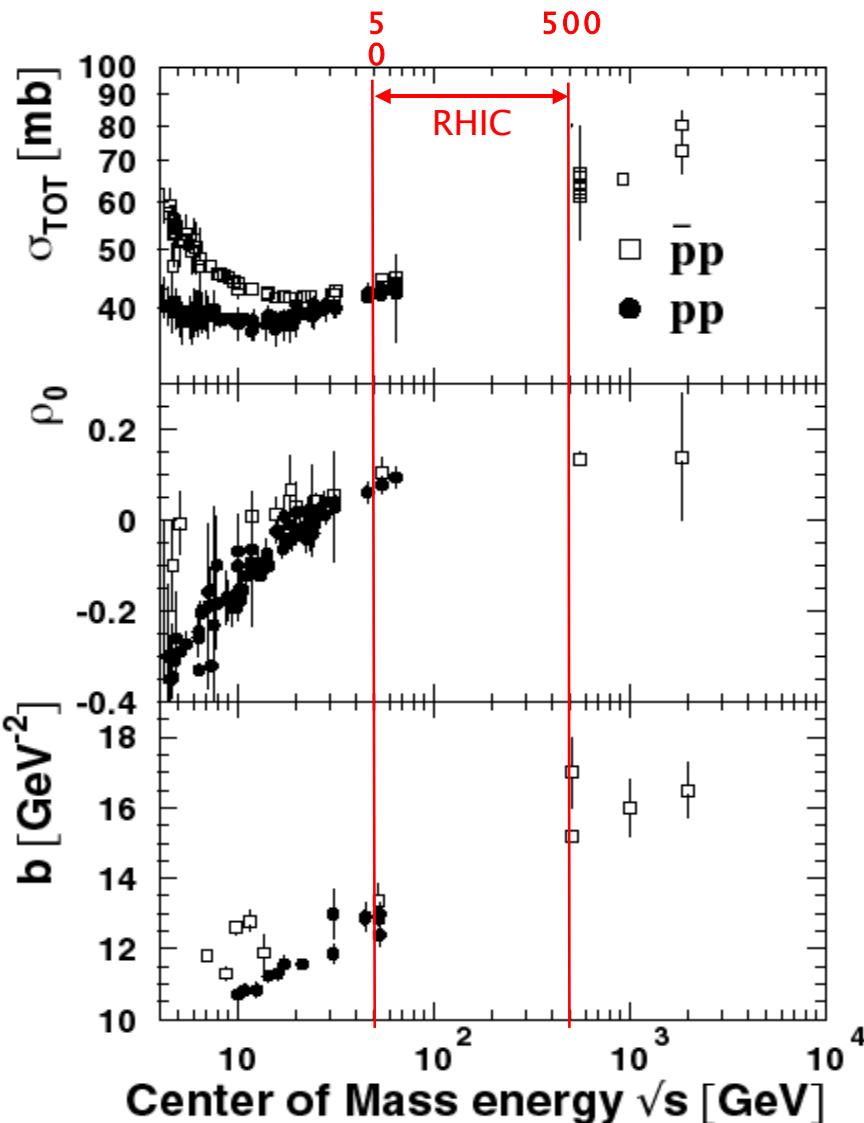
- A_N interference between hadronic non-flip amplitude and electromagnetic spin-flip amplitude.

$$A_N(t) = \frac{\hat{\sigma}(t) - \bar{\sigma}(t)}{\hat{\sigma}(t) + \bar{\sigma}(t)} \propto \frac{\text{Im}[\phi^* \phi]}{d\sigma dt}$$

- Properties of constituent quark structure $\phi = r_5(s) \frac{\sqrt{-t}}{m_p} \text{Im} \frac{1}{2} (\phi + \bar{\phi}) = r_5(s) \frac{\sqrt{-t}}{m_p} \text{Im} \phi$
- Magnitude of the Pomeron spin-flip

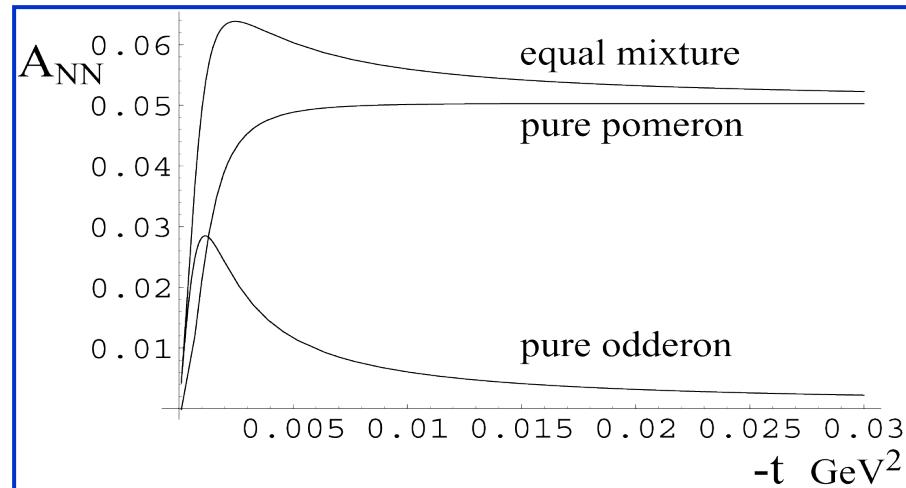


Existing Data



- Highest energy so far:
 - pp: 63 GeV (ISR)
 - pp: 1.8 TeV (Tevatron)
- RHIC energy range:
 - $50 \text{ GeV} \leq \sqrt{s} \leq 500 \text{ GeV}$
- Elastic measurements:
Details on the nature of elastic scattering at high energy are not well understood
 - STAR/RHIC has an unique chance to do measurements in wide t -range with polarized beams

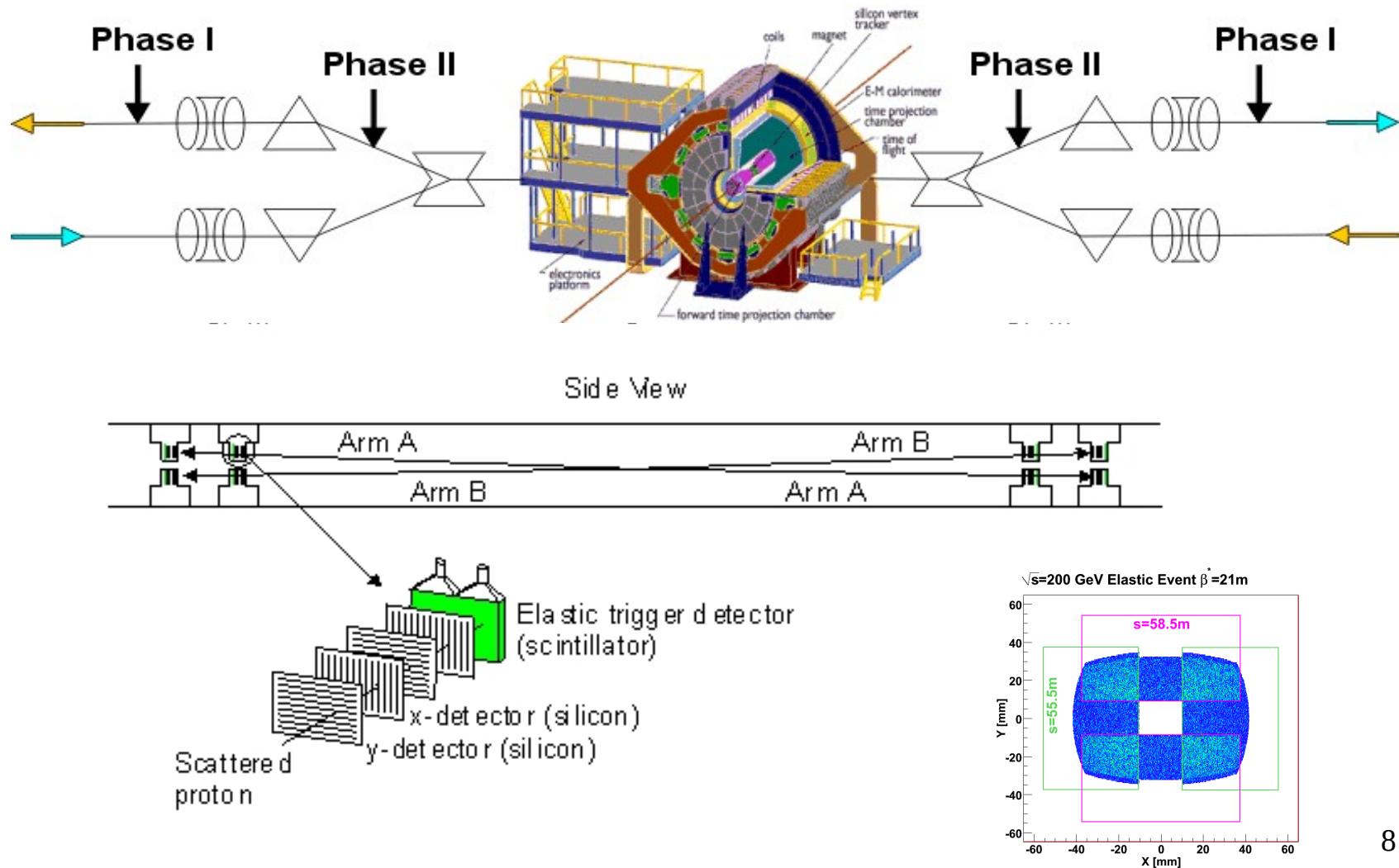
Odderon at RHIC?



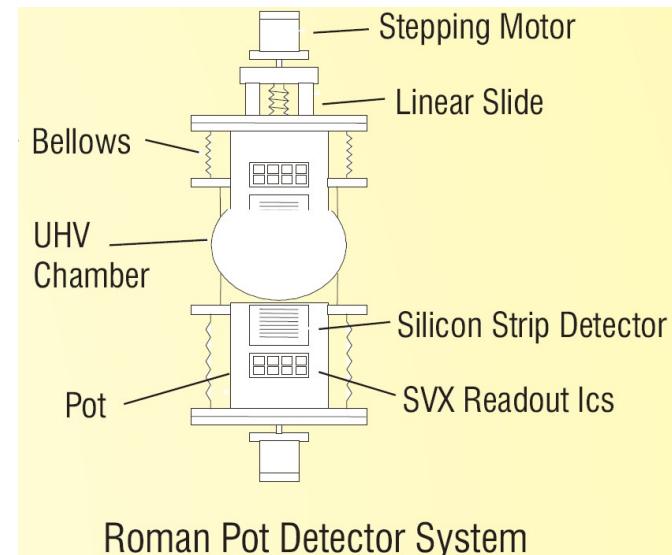
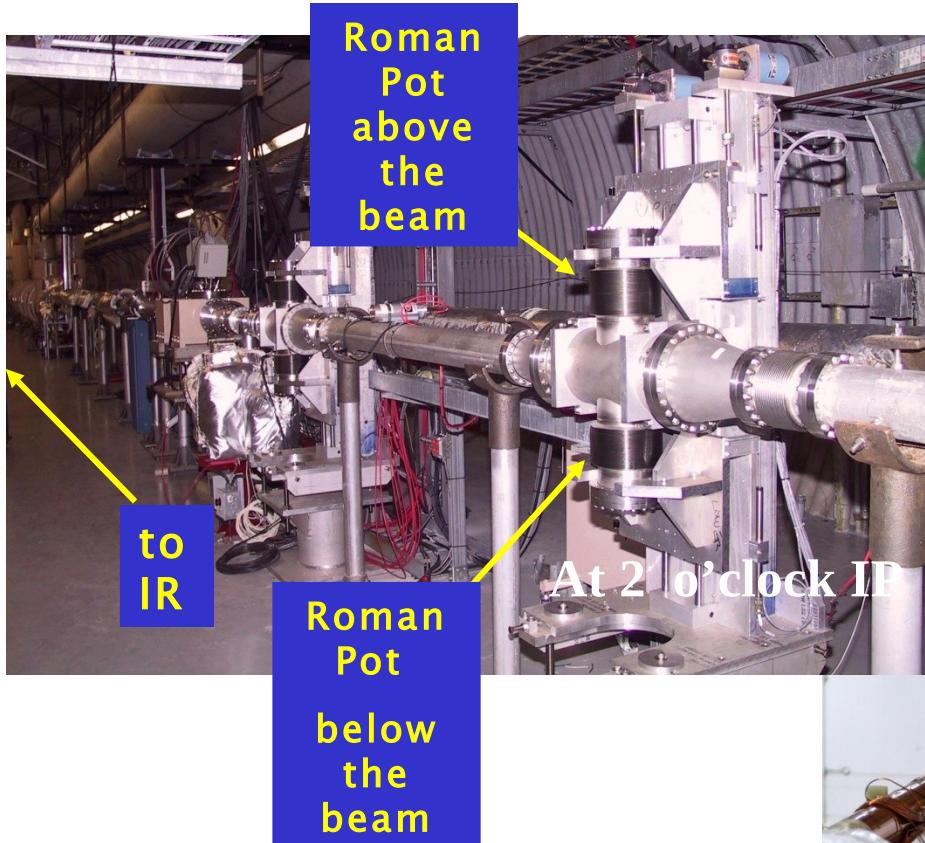
- Leader, Trueman PRD 61 (2000),
[hep-ph/0604153](https://arxiv.org/abs/hep-ph/0604153)

- Odderon is a counterpart of pomeron ($C=+1$) with $C=-1$: “RHIC is the machine to find it” (E. Leader, Odderon Workshop (2005)) by measuring
 - $\Delta(\sigma_{pp} - \sigma_{pp(\bar{p})}) \neq 0$ ($\sim 3\text{mb}$)
 - $d\sigma/dt_{pp} \neq d\sigma/dt_{pp(\bar{p})}$
- Shape of Asymmetries: A_{NN}
- Centrally produced $C=-1$ particle

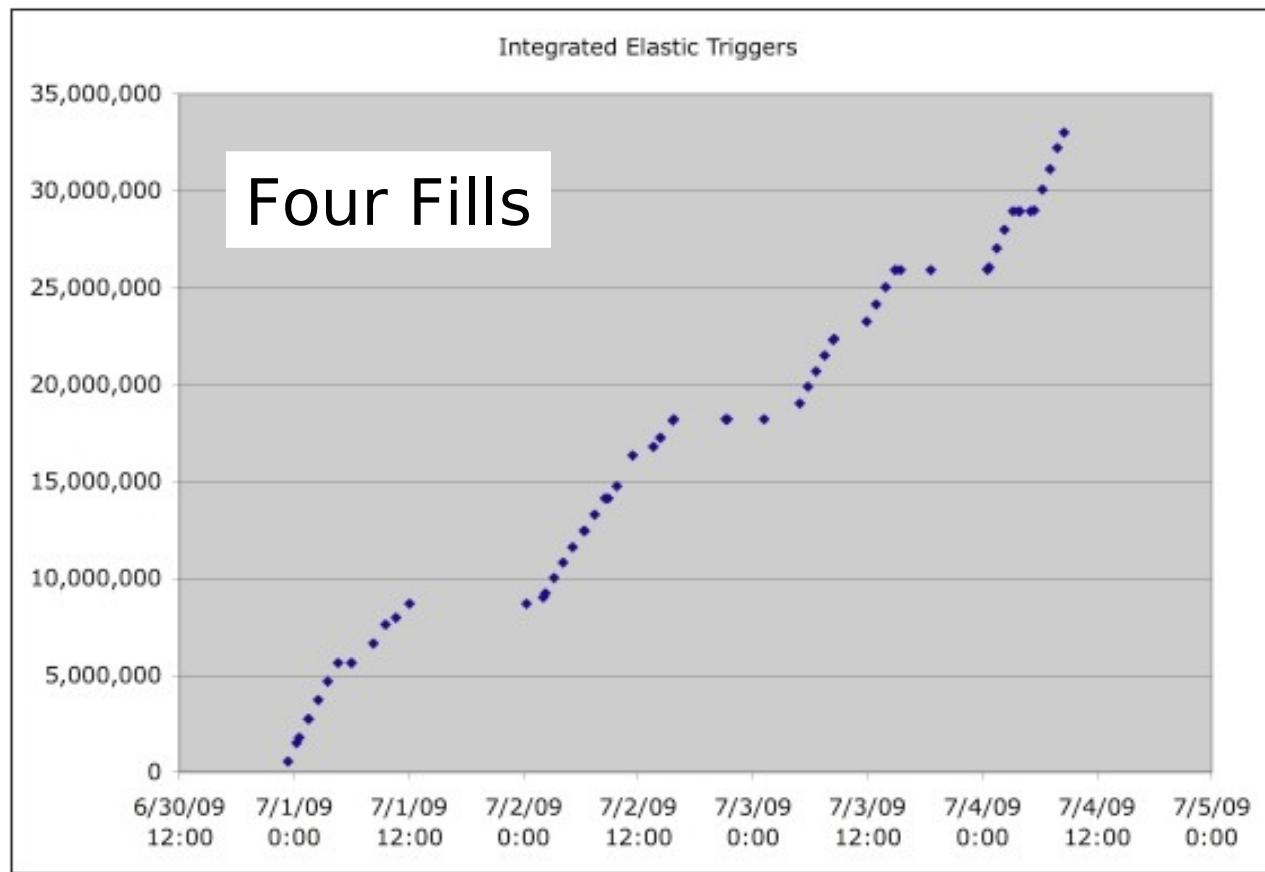
Tagging Forward Protons with RP



Experimental Setup

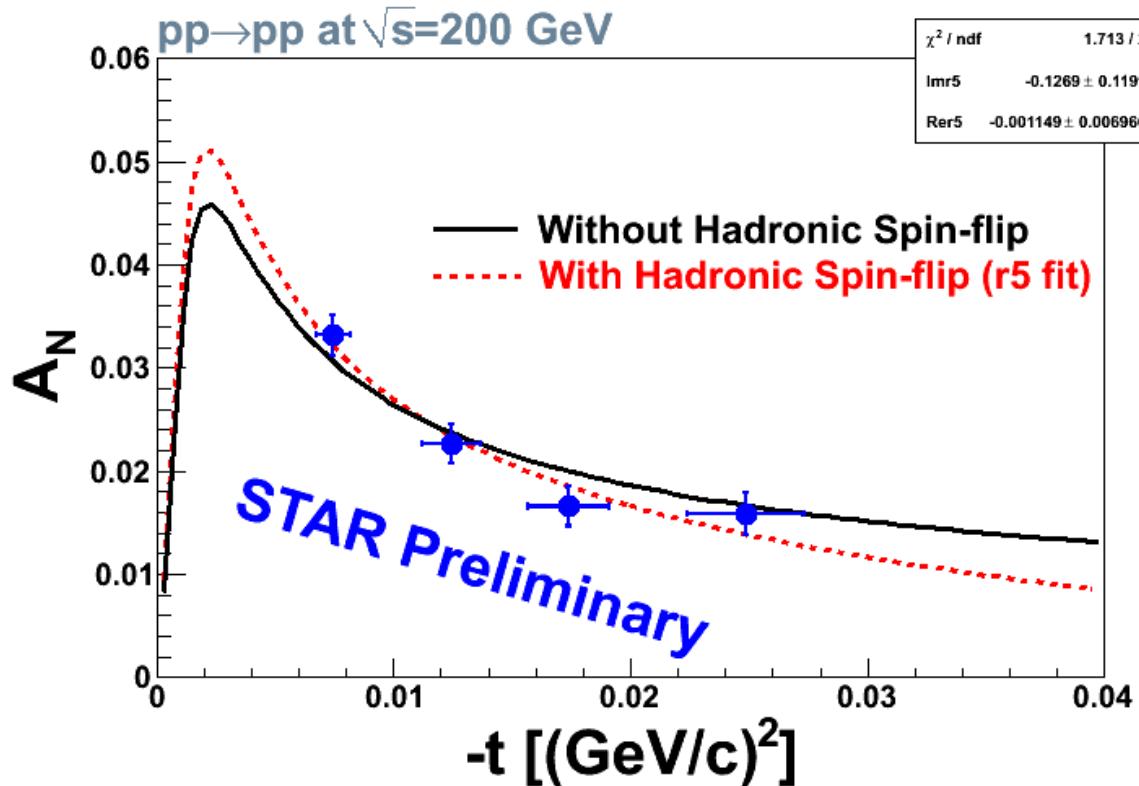


RUN 09



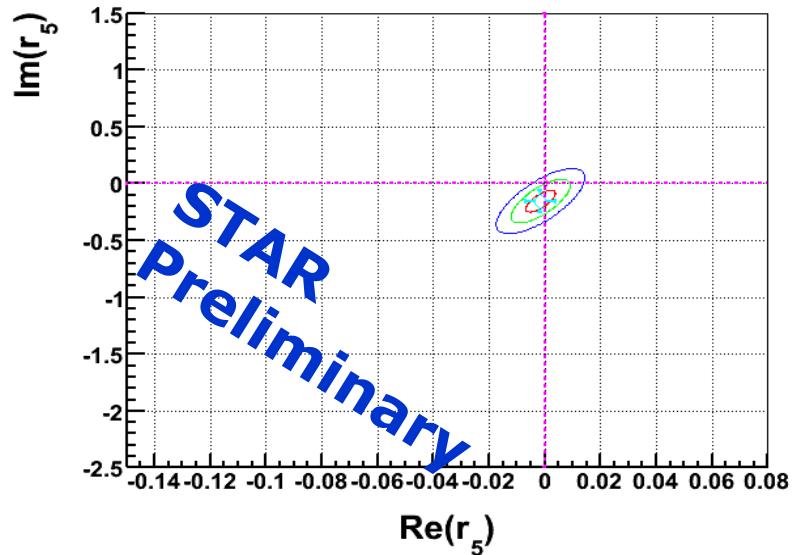
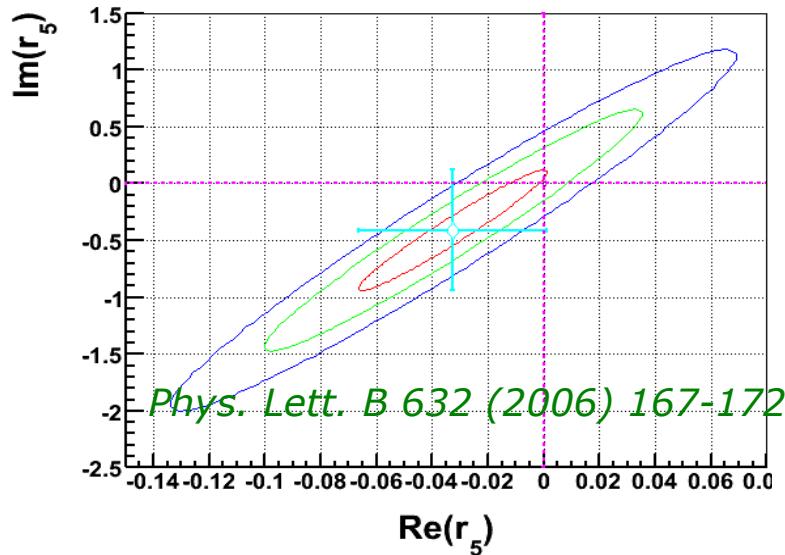
- Successful RUN 09
 - 33M elastic events
 - 0.7 M central events

A_N measurement at $\sqrt{s}=200$ GeV



- Statistical errors + systematic t -scale uncertainty (10%) in the fit
- Higher- t during upcoming $\sqrt{s}=500$ GeV (and with Phase II set-up) at RHIC

Hadronic spin-flip contamination

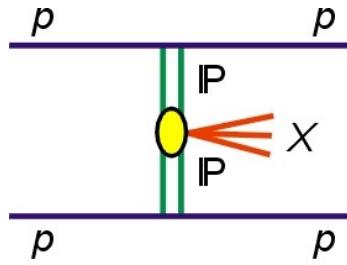


- Fit to the data with hadronic spin-flip (r_5 -fit)
 - relative amplitude between hadronic spin-flip (Φ_5) and non-flip (Φ^+) helicity amplitudes

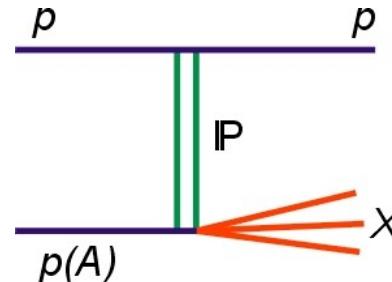
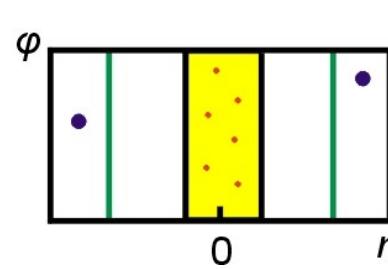
$$r_5 = \text{Re } r_5 + i \text{Im } r_5 = \frac{m \phi}{\sqrt{-t} \text{Im } \phi_+}$$

- No significant hadronic spin-flip required in the fit

Inelastic Program



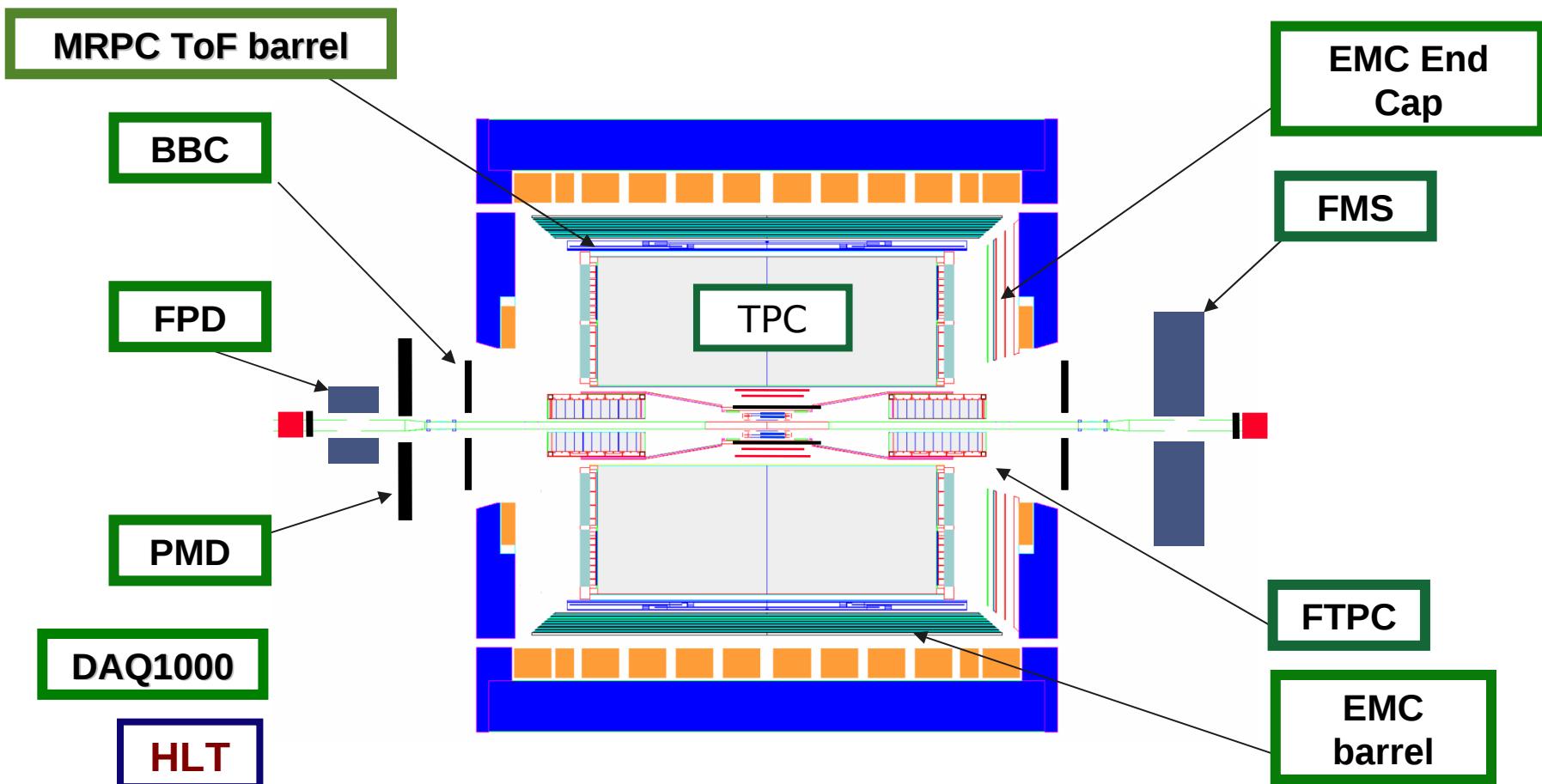
Double Pomeron Exchange (DPE)



Single Diffraction Dissociation (SDD)

- Candidates with conventional quantum numbers: need to be studied in wide kinematic ranges
- Gluonic degree of freedom in Hadrons – exotica (glueballs...)
- Nature of diffractive processes – structure of Pomeron, Odderon...

Current Experimental Configuration

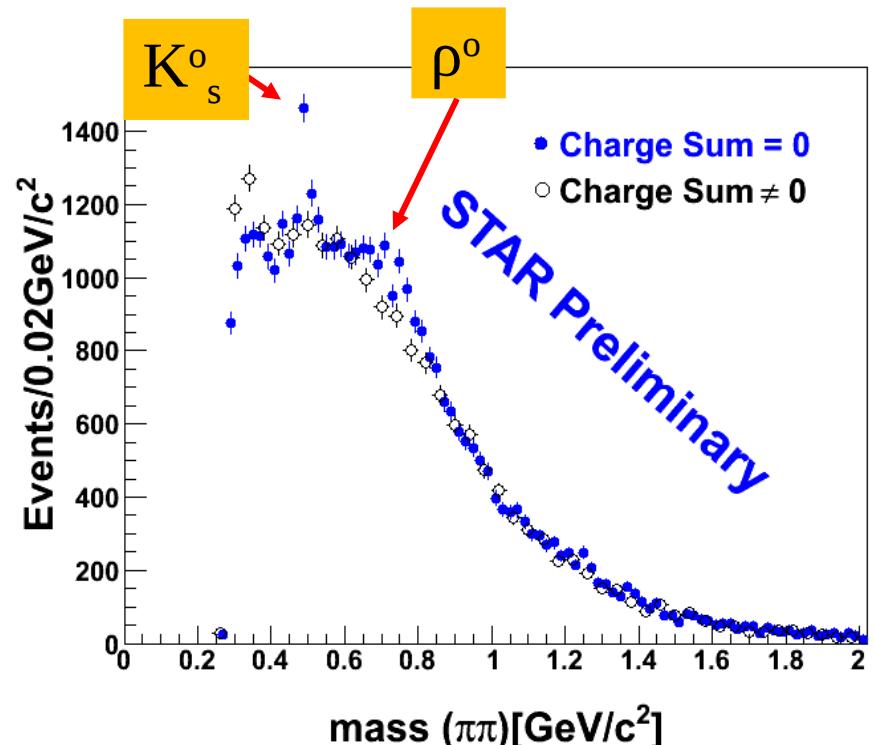
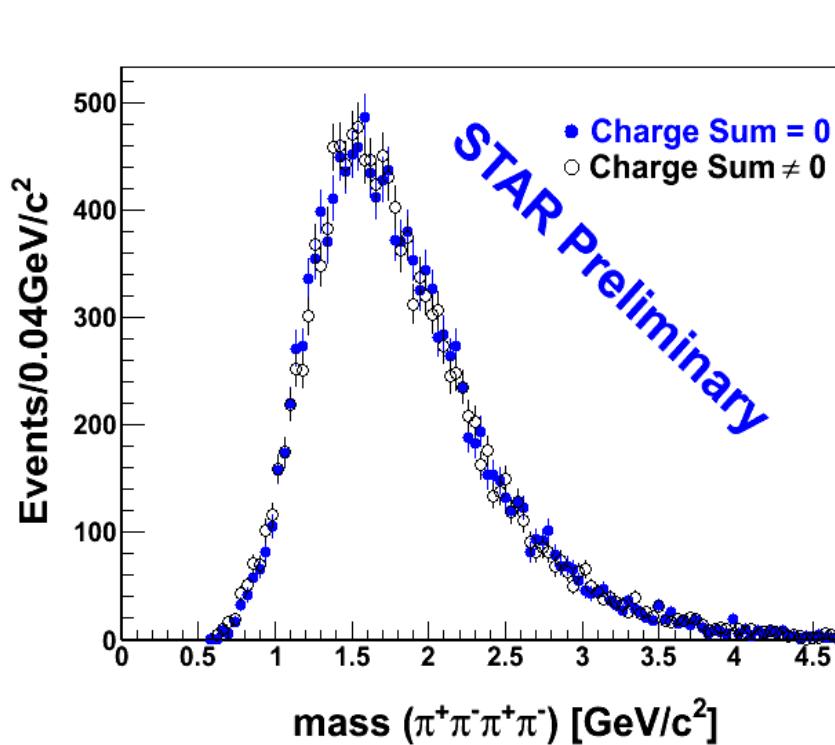


Tracking capabilities in $-1 < \eta < 1$ and $-\pi < \phi < \pi$
Particle identification via TPC dE/dx and ToF
Rapidity gap triggering with BBC

Preliminary results from Run 09

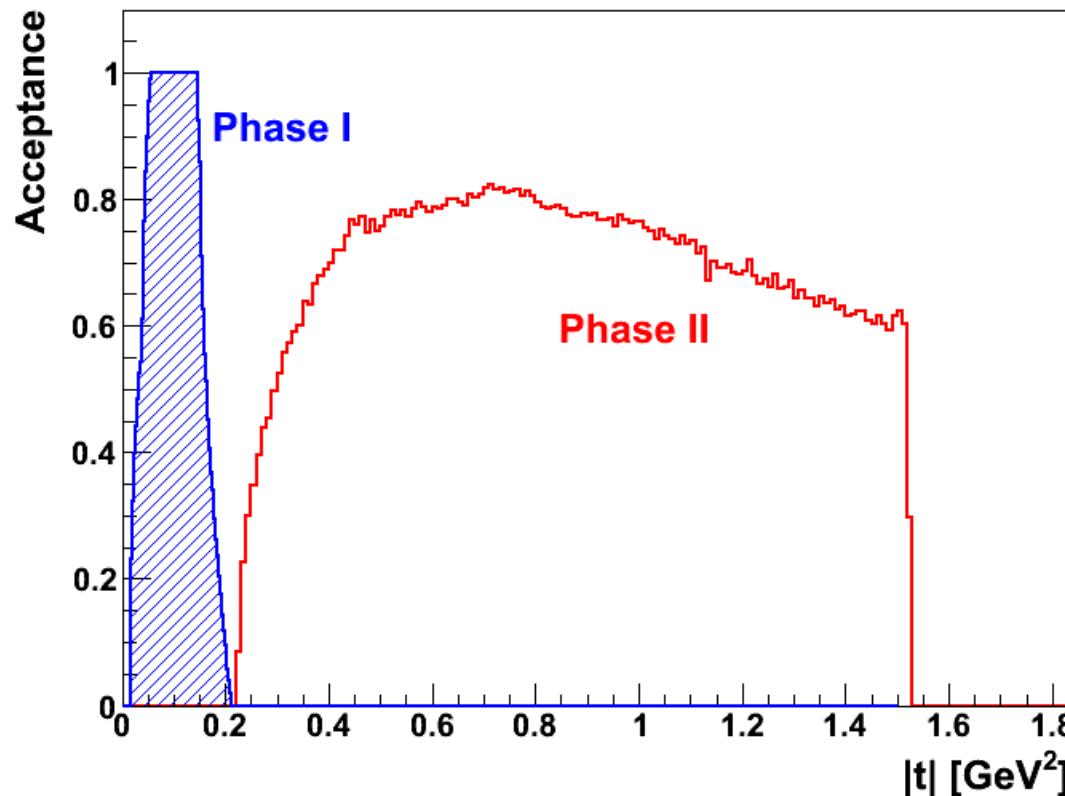


Triggering : ToF+RP, Tracking : TPC , All candidates



- Collected 700k Central Production triggers during run 09
 - Trigger : RP & TOF
 - Work in progress: pid, rapidity gap, p_T , missing mass, ...
- The main data taking is planned during Phase 2

Kinematics in Phase II



- Measuring scattered protons with Roman Pot system
 - Low t accessible in Phase 1 for elastic
 - High t will be targeted in phase 2 for elastic

Summary

- Very successful RUN 09
 - 33 M elastic events , 0.7 M central events
- First high statistics data at high energy of spin asymmetries in CNI region
 - Elastic scattering - spin dependence A_{NN} , A_N , A_{SS} , A_S , $\Delta\sigma_{tot}$ for the spin combinations.
 - Elastic scattering - spin slope b , σ_{tot} , ρ , luminosity measurements.
 - Diffraction - Central Production, Single Diffraction Dissociation and its spin dependence.
- Working on finalizing preliminary results
- Phase II proposal has been approved by the STAR collaboration and received high priority among future upgrades

Backup



Implementation at STAR



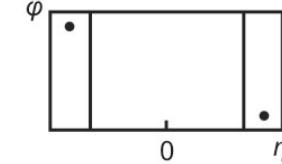
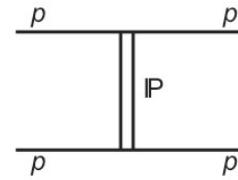
Elastic triggers (co linearity) - Roman Pots only:

- Vertical (up \wedge down) (down \wedge up)
- Horizontal: (left \wedge right) (right \wedge left)

The data with this trigger is recorded through its own path using STAR DAQ and trigger hardware.

Elastic trigger rate 400 Hz.

Elastic Scattering



Inelastic triggers (Central Production) -

RP + CTB/ToF; Need to readout TPC

For example:

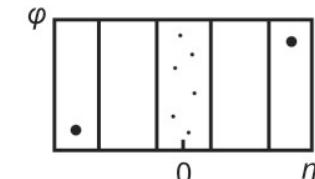
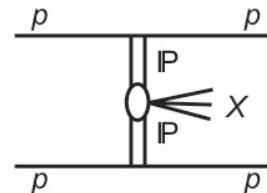
- ((up \wedge up) or (down \wedge down)) + CTB/ToF
- ((left \wedge left) or (right \wedge right)) + CTB/ToF

CP trigger rate \sim 10 Hz

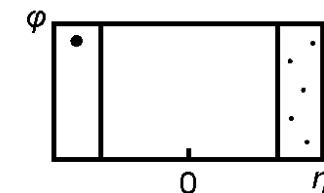
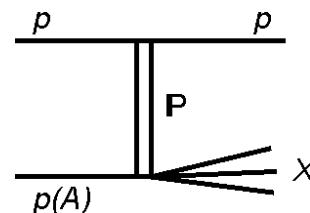
Inelastic triggers (Single Diffraction):

RP + FMS or RP + BBC

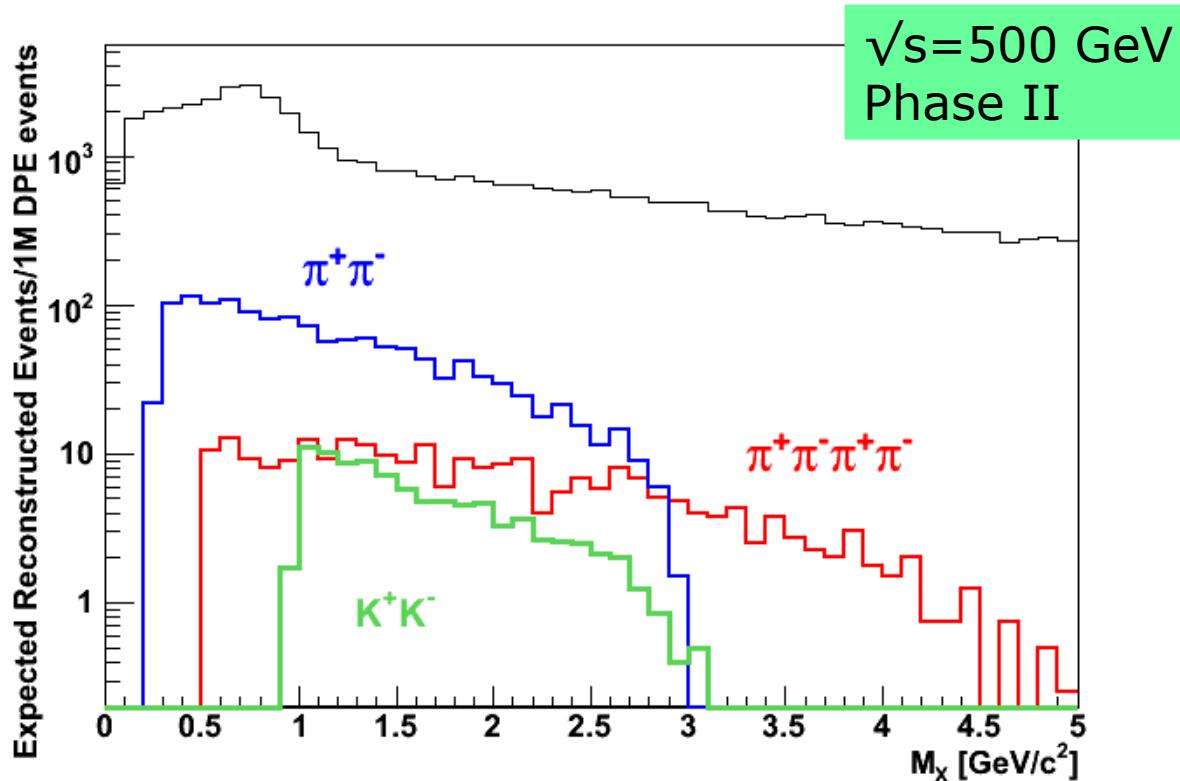
Central Production



Single Diffraction

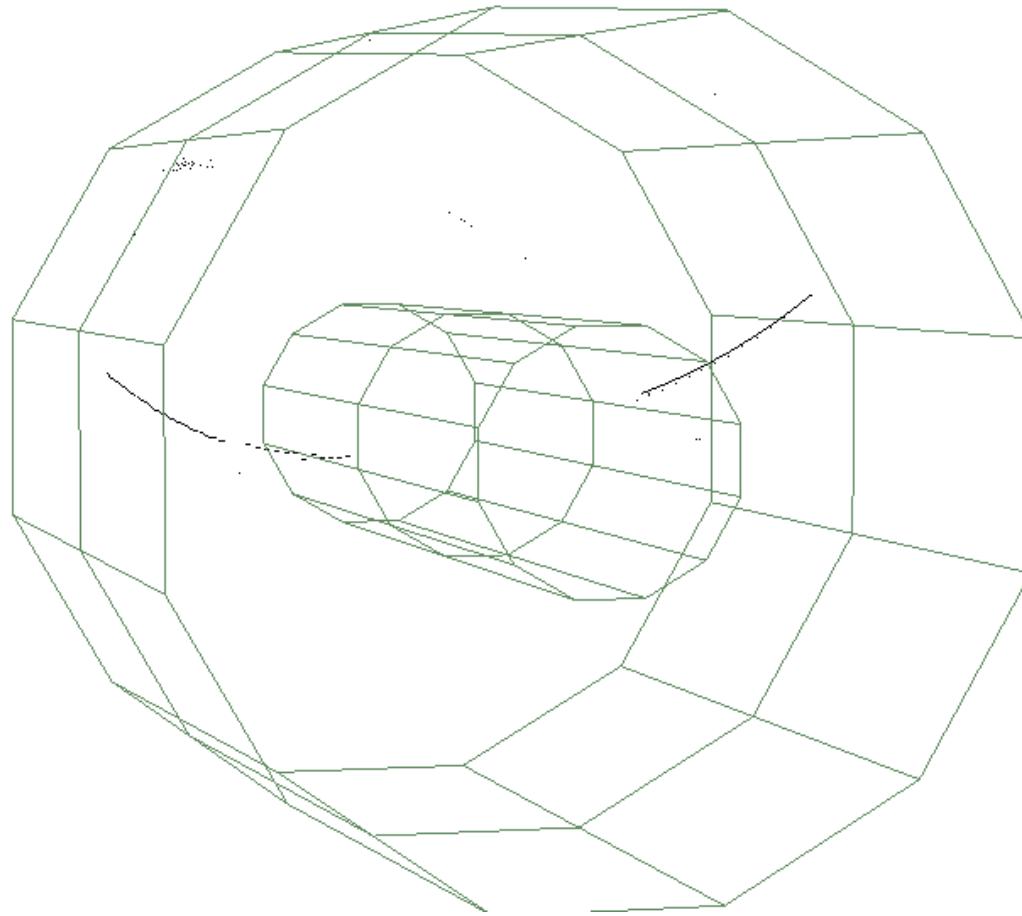


Phase II



- **Expected reconstructed phase-space** including 140 μbarn Crosssection
and branching ratios measured at ISR per 25M DPE
- Expected Trigger rate for DPE: $\sim 100 \text{ Hz}$ at $L=1 \times 10^{31} \text{cm}^{-2}\text{s}^{-1}$
 - 20 Week RHIC running: $\sim 2\text{M } K^+K^- \sim 6\text{M } \pi^+\pi^-\pi^+\pi^-$ sample

Central Production





Experimental Determination of A_N

$$2\pi \frac{d^2\sigma}{dt d\varphi} = \frac{d\sigma}{dt} \cdot (1 + (P_B + P_Y) A_N \cos \varphi + P_B P_Y (A_{NN} \cos^2 \varphi + A_{SS} \sin^2 \varphi))$$

$$\varepsilon_N(\varphi) = \frac{(P_B + P_Y) \cos \varphi \cdot A_N}{1 + \delta} = \frac{\sqrt{N_L^{\uparrow\uparrow}(\varphi) N_R^{\downarrow\downarrow}(\pi - \varphi)} - \sqrt{N_R^{\uparrow\uparrow}(\pi - \varphi) N_L^{\downarrow\downarrow}(\varphi)}}{\sqrt{N_L^{\uparrow\uparrow}(\varphi) N_R^{\downarrow\downarrow}(\pi - \varphi)} + \sqrt{N_R^{\uparrow\uparrow}(\pi - \varphi) N_L^{\downarrow\downarrow}(\varphi)}}$$

Asymmetry

$$\varepsilon_F(\varphi) = \frac{(P_B - P_Y) \cos \varphi \cdot A_N}{1 - \delta} = \frac{\sqrt{N_L^{\uparrow\downarrow}(\varphi) N_R^{\downarrow\uparrow}(\pi - \varphi)} - \sqrt{N_R^{\uparrow\downarrow}(\pi - \varphi) N_L^{\downarrow\uparrow}(\varphi)}}{\sqrt{N_L^{\uparrow\downarrow}(\varphi) N_R^{\downarrow\uparrow}(\pi - \varphi)} + \sqrt{N_R^{\uparrow\downarrow}(\pi - \varphi) N_L^{\downarrow\uparrow}(\varphi)}}$$

“False”
Asymmetry

$$\delta(\varphi) = P_B P_Y (A_{SS} \cos^2 \varphi + A_{NN} \sin^2 \varphi) < 0.03$$



Cross sections for polarized beams

Cross-section, azimuthal angular dependence for transversely polarized beams, with polarizations P_B and P_y :

$$A_N = A_N(P_B \cdot P_Y) \cdot n = A_{NN}(P_B \cdot n)(P_Y \cdot n) - A_{SS}(P_B \cdot s)(P_Y \cdot s)$$

$$A_N = \frac{\sigma^{\uparrow\downarrow} - \sigma^{\downarrow\uparrow}}{\sigma^{\uparrow\downarrow} + \sigma^{\downarrow\uparrow}} \text{ is a single spin asymmetry}$$

where σ^{\uparrow} is a cross section for one beam fully polarized along the scattering

$$A_{NN} = \frac{\sigma^{\uparrow\uparrow\downarrow\downarrow} - \sigma^{\downarrow\downarrow\uparrow\uparrow}}{\sigma^{\uparrow\uparrow\downarrow\downarrow} + \sigma^{\downarrow\downarrow\uparrow\uparrow}} \text{ double spin asymmetry}$$

where $\sigma^{\uparrow\uparrow\downarrow\downarrow}$ is a cross section with both beams fully polarized normal to the scattering plane

A_{SS} has the same definition, the $\sigma^{\uparrow\uparrow\downarrow\downarrow}$ is a cross section for two beams fully polarized along the normal to the scattering plane

$$s = \frac{n \times p}{|n \times p|}, \text{ where } \vec{n} \text{ is beam momentum}$$

RHIC Accelerator Complex

